Investigation of Local Effects on Microstructure Evolution

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The principal reason for processing materials in the microgravity environment is to obtain improved material properties. These properties are generally related to the purity and microstructural morphology of the bulk material. Results from early space-processed materials showed the inadequacy of the then-current models for predicting microstructure. Of the many parameters that influence development of microstructure, this effort concentrates on the diffusive mass transport between droplets in a two-phase system. Of particular interest is the local environment around a growing or shrinking droplet (the number and spacing between droplets in the immediate neighborhood of a given droplet). The primary goal of this work is to improve understanding of microstructure evolution in solidifying materials. The approach uses data from experiments on transparent materials to develop better predictive computer models.

The effort, to date, has resulted in experimental observation of diffusional coarsening among a finite cluster of precipitates forming spherical caps on the wall of a thin cell in a liquid-liquid system using a holographic technique. Numerical modeling of the process using the multipole expansion method and the assumption of two-dimensional diffusion fields has yielded good agreement with experimentation. Both monopole and dipole approximations closely follow the experimentally observed scaling laws characteristic for mixed-dimensional coarsening, i.e., three-dimensional droplets and two-dimensional diffusion fields. N^{-43} and R^4 varied linearly with time, where N is the number of droplets in the experimental field of view, and R is the average droplet radius.

Experimental observations of dynamic local behaviors within the context of a particle ensemble are accessible by optical techniques, including holography. The evolution of individual droplets in two- and three-dimensional diffusion fields is under study. Mixed dimensional systems have droplets tethered by the cell surfaces, and collection of a considerable amount of ground-based data, avoiding sedimentation, is possible. The more difficult unit-gravity experiment is the three-dimensional case, in which sedimentation is also a problem, as well as buoyancy-driven convection. A flight experiment for this case is under consideration.

The research team has developed a multipole representation of sources and sinks to represent interacting droplets. It has been noted that screening effects occur that are analogous to the Debye-Huckle theory of ionic solutions in which potential sinks and sources are not uniformly distributed. Measurements of droplet-size distribution and droplet location for a larger area of the experiment test cell are in progress using holograms taken during the experiment. Using holography eliminates questions about whether experimental conditions were consistent from experiment to experiment. Data will elucidate the effect of screening length on the diffusive growth rates. Experiments using a limited number of tethered droplets are underway. Measurements of growth rates at different temperatures, and hence different density gradients, will clarify the effect of convection on the ripening process.

A better understanding of the parameters affecting development of the microstructure should lead to improved processes to form industrially important materials with enhanced properties. Properties such as conductivity, structural integrity, and homogeneity are all influenced by microstructure. The team has shown that local effects—enhanced by holographic techniques—deviate significantly from global behavior predictable by Lifshitz, Slyozov, and Wagner. These deviations can be important in predicting material microstructure.

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